

HabitatSpace: Multidimensional Characterization of Pelagic Essential Fish Habitat

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Abstract- Habitat is recognized as crucial to the survival and recovery of exploited species. Climate change, environmental variability, and increased anthropogenic modification of the oceans add a sense of urgency to the correct identification, monitoring and conservation of essential fish habitat. Identifying essential habitat in three dimensions is the first step in being able to react to changes in environment caused by any of these drivers. Extending tools for essential fish habitat (EFH) analysis to higher dimensions would greatly enhance the ability of scientists to evaluate and respond to climate change. The ability to create these types of analyses for pelagic species will improve our ability to support integrated ecosystem assessments (IEA).

Geographic information systems (GIS) have provided many of the tools used to delineate EFH. These tools work very well for the characterization of benthic EFH, but are less usable for identifying pelagic EFH. HabitatSpace will extend the 2-D tools used for EFH to a suite of 3-D tools to strengthen analysis capabilities within the pelagic zone.

Through a strategic partnership with the Northern Gulf Institute, Ecosystem Data Assembly Center services will be leveraged and extended to ingest a range of ecosystem data, transform data to standard, open source formats, and serve data via the THREDDS Data Server. The HabitatSpace client will operate on the end user's desktop as either an ESRI ArcGIS extension or as a stand alone client. New analysis tools will be developed and integrated with existing features to broaden overall scientific analysis capabilities. The result will be a robust analysis tool suite that will enable the scientist to: a) create a convex hull for calculating habitat volumes; b) calculate volume on volume intersections; and c) calculate the intersection of paths taken by larvae through in situ data to create predicted temperature histories.¹

I. INTRODUCTION

Habitat is recognized as crucial to the survival and recovery of exploited species. In 1996, Congress added new habitat provisions to the Magnuson-Stevens Fishery Conservation and Management Act² (MSA), the federal law that governs U.S. marine fisheries management. Under the Magnuson-Stevens Act, each fishery management plan must describe and identify essential fish habitat (EFH) for the fishery, minimize the adverse effects of fishing on EFH, and identify other actions to encourage the conservation and enhancement of EFH. Climate change, environmental variability, and increased anthropogenic modification of the oceans add a sense of urgency to the correct identification, monitoring and conservation of essential fish habitat. Identifying essential habitat in three dimensions (3D) is the first step in being able to react to changes in environment caused by any of these drivers. Extending tools for EFH analysis to

Main Entry: **hab-i-tat**

Pronunciation: \ 'ha-bə-tat \

Function: *noun*

Etymology: Latin, it inhabits, from *habitare*

Date: 1796

1 a: the place or environment where a plant or animal naturally or normally lives and grows **b:** the typical place of residence of a person or a group **c:** a housing for a controlled physical environment in which people can live under surrounding inhospitable conditions (as under the sea)

Merriam-Webster Online Dictionary

¹ This research is partially funded by NOAA's High Performance Computing and Communications Program http://www.cio.noaa.gov/HPCC/hpcc_major_activities.html;

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² The MSA is the primary law governing marine fisheries management in United States federal waters (accessed 8/28/09) .<http://www.nmfs.noaa.gov/sfa/magact/>

higher dimensions would greatly enhance the ability of scientists to evaluate and respond to climate change. The ability to create these types of analyses for pelagic species will improve their ability to support integrated ecosystem assessments (IEA).

With the passage of the Sustainable Fisheries Act (Public Law 104-297), which amended the Magnuson Act to become the Magnuson-Stevens Act in 1996, NOAA has a mandate to identify habitat essential to fisheries species. Under the wording of the Act, essential habitat means “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” For the purpose of interpreting the definition of essential fish habitat: “waters” includes aquatic areas and their associated physical, chemical, and biological properties that are used by fish, and may include areas historically used by fish where appropriate; “substrate” includes sediment, hard bottom, structures underlying the waters, and associated biological communities; “necessary” means the habitat required to support a sustainable fishery and a healthy ecosystem; and “spawning, breeding, feeding, or growth to maturity” covers a species’ full life cycle.

The Magnuson-Stevens act also provides a definition of habitat for both benthic and pelagic species. “From the broadest perspective, fish habitat is the geographic area where the species occurs at any time during its life. That area should be described in terms of ecological characteristics including biological, physical, and chemical parameters, location, and time. Ecologically, essential habitat includes structure or substrate that focuses distribution (e.g., coral reefs, marshes, or kelp beds) and other characteristics that are less distinct (e.g., turbidity zones, thermoclines, or fronts separating water masses). Spatially, habitat use may shift over time due to climatic change, human uses, or other factors. Habitat not currently used should be considered when establishing long-term goals for EFH and species productivity. Habitat restoration will be a vital tool to recover degraded habitats, improve habitat quality and quantity, with benefits to the species and society.”

II. USING GIS TO DELINEATE HABITAT

For many scientists, habitat is thought to be primarily a 2 or 2.5-dimensional (2D) feature. For example, seagrass (Fig. 1) is a typical habitat. It grows on the seafloor and is basically a 2-D substrate. Fish that rely on this habitat interact with it as though it were a surface. The distribution of seagrass is controlled by features such as bottom sediment type and the slope of the seafloor.

Geographic information systems (GIS) have provided many of the tools used to delineate these types of essential habitats. These tools can overlay a number of layers defining areas of optimal values for parameters such as bottom type, slope and current speeds to define an area of “best” habitat. Examples of tools in common use include Marxan for designing ecological reserves, Habitat Digitizer to delineate spatial features, and EcoPath/EcoSim to model ecosystems and predict the spatial pattern of system components.³



Figure 1 Example of 2-D seagrass habitat

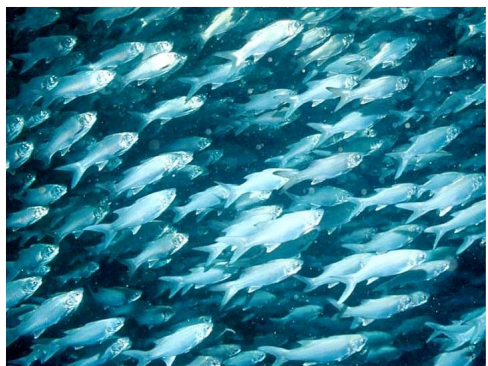


Figure 2 Example of a pelagic fish in a 3-D habitat

GIS tools work very well for the characterization of benthic EFH, but benthic habitats represent only part of the oceanic habitat. For fish in the open ocean the environment is fully multidimensional (Fig. 2). Variations in water column properties, such as salinity and temperature, combined with location and time make their habitat a fully four-dimensional (4D) entity. The optimal habitat for a pelagic species, or a specific life stage such as a larval fish, may be defined by a combination of factors. For example, certain larvae prefer water temperatures between 5 and 7 degrees C, salinities between 33 and 34 PPT and depths below the turbulent surface layers, but above 50m depth.

Scientists want to calculate the intersection of the volumes defined by these (or similar) criteria. For example, temperature history, more than just temperature at a given moment in time, affect larval development. Scientists want to integrate *in situ* temperature data with model output to create a temperature time series for the habitat and the pelagic larvae in it. Additional functionality, beyond traditional GIS tools, is needed to visualize and analyze these and similar scenarios.

HabitatSpace [1] is a software tool designed to extend the concept and the tools available for 2D habitat delineation to multiple dimensions, so that volumetric and statistical analyses can be made. The work is partially based upon the results, some

³ Marxan - <http://www.uq.edu.au/marxan/>, HabitatDigitizer - <http://ccma.nos.noaa.gov/products/biogeography/digitizer/>, EcoPath/EcoSim – www.ecopath.org, all viewed 8/25/09

promising and some lacking, of previous investigative research conducted by the Authors into various technologies required to accomplish these tasks [2] [3]. Existing routines now allow us to calculate oceanographic parameters such as the mixed layer depth, integrate datasets, display the trajectories of larval fish based upon model data, and visualize the results. Other routines calculate the intersection of the trajectories with planar features. NetCDF⁴ files can now be read and written as a native format in many geospatial visualization tools, standardizing data access and minimizing the need for data transformations. These various capabilities, all necessary to solve elements of the problem set, are not readily found in one software tool.

The intent of HabitatSpace is to bring these technologies together in an easy-to-use, familiar and cost effective interface that will allow scientists to focus on science instead of information technology (IT) development. To accomplish this task, various software tools were evaluated and two were selected for additional customization. A plan was formed to develop a common framework for data access, and similar capabilities in each tool as fully as possible. A post-development comparison is planned. Although development is still ongoing at the time of this writing, enough work has been completed to provide a limited summary of results.

III. DEVELOPMENT FRAMEWORK

Goals for the HabitatSpace client were, simply stated, to integrate in situ, model and biological data to define habitats, and to provide a framework for multidimensional visualization and statistical analysis of these Habitats. Desirable functions were outlined as follows:

- Interactive, intuitive display
- User defined, iterative ranges for organisms
- Ability to shape characterizations
- Multi-dimensional visualization of pelagic habitat
- Display path of organism through habitat
- Statistical comparison of habitats

A. Technical Considerations for selection of the HabitatSpace Client application software framework

An important consideration in the selection of a base software package for HabitatSpace development was the prior investment made by the authors in customizing ESRI® ArcGIS™ software with VTK⁵ in an effort to integrate traditional geospatial data with model data for visualization and analysis [2].

The ESRI® software suite is a widely used, very capable GIS package with an intuitive, readily modifiable UI. In past efforts, results have proven less than optimal due primarily to the size of the resultant code base, making new user installation almost prohibitively difficult for the average user. Another important concern was the less than optimal user interface (UI) that resulted from trying to integrate external elements into the commercial product interface. In thinking about methods to lighten up the client code base and to develop a more intuitive UI, the authors initially planned to create a tool entirely using ArcGIS™ and ArcObjects™. To mitigate concerns about software licensing costs and to increase portability, the development of an ArcGIS™ Engine⁶ application, requiring a less expensive runtime license, was planned. An ArcGIS™ desktop extension, designed to enable users to ingest the necessary data sets while at the same time allowing licensed ESRI® users to take advantage of the inherent ArcGIS™ functions for statistical analysis and multidimensional display, was also planned.

Because of the multidimensional visualization requirements, and concerns about the basic limits of the packaged ArcGIS™ suite functionality to meet these requirements, the authors elected to perform the same set of tasks using a second software suite with different strengths. The idea evolved to develop a second version of the HabitatSpace client using a software suite with native 3D capacity. The idea was to approach the problem set – ease of data ingest and display; multidimensional and statistical analysis – from opposite ends of the development spectrum to determine which approach would provide an outcome with the least compromise in usability and functionality.

A number of software tools were evaluated, particularly for strength in visualizing multidimensional data. Results are summarized in Table 1. After making these comparisons, the Integrated Data Viewer⁷ (IDV) tools from Unidata were selected, primarily due to the balance of speed, ease of installation, and functionality. Cost effectiveness and technical support were also important considerations.

⁴ NetCDF (network Common Data Form) is a set of interfaces for array-oriented data access that support the creation, access, and sharing of scientific data. (last accessed 8/28/09) <http://www.unidata.ucar.edu/software/netCDF/>

⁵ VTK is an open-source software system for 3D computer graphics, image processing and visualization (last accessed 8/28/09) www.vtk.org

⁶ ESRI (last accessed 8/28/09) <http://resources.esri.com/arcgisengine/>

⁷ The Integrated Data Viewer (IDV) from Unidata is a Java(TM)-based software framework for analyzing and visualizing geosciences data. (Last accessed 8/28/09) <http://www.unidata.ucar.edu/software/idv/>

Table 1 Comparison of tools for multidimensional data visualization

Tools	Advantages	Disadvantages
VisIt/Paraview	<ul style="list-style-type: none"> - Powerful tools: <ul style="list-style-type: none"> - Slice and dice; Constructed Expressions; Resample data - Faster, VTK based rendering - Reader Plugins: C++ - Install is easy once additions are part of public binary release - Java support in development 	<ul style="list-style-type: none"> - Netcdf C libs – not java! - Overkill for HabitatSpace: <ul style="list-style-type: none"> - Designed for tera scale; Parallel processing; Bigger more complex app - Limited geospatial support
Mathworks with compiler	<ul style="list-style-type: none"> - Matlab compiler allows distribution of executables - Designed for command line not complex graphics/GUIs - Allows access to data structures and analysis - Has NetCDF Java toolbox 	<ul style="list-style-type: none"> - Limited Geospatial support - Slow rendering - Expensive
Vis5D	<ul style="list-style-type: none"> - Very powerful visualization package - C compiler package for unix/linux 	<ul style="list-style-type: none"> - Unsupported since ~2002 - Limited geospatial support
TechPlot10:	<ul style="list-style-type: none"> - Very powerful commercial product for CFD 	<ul style="list-style-type: none"> - NetCDF not supported - Difficult to customize - Expensive
Fledermaus	<ul style="list-style-type: none"> - Very powerful commercial product for 3D GIS 	<ul style="list-style-type: none"> - NetCDF support is limited - Difficult to customize - Expensive
Integrated Data Viewer (IDV)	<ul style="list-style-type: none"> - Powerful tools: <ul style="list-style-type: none"> - Slice and dice; Constructed Expressions; Resample data - Netcdf Java <ul style="list-style-type: none"> - Web access - Built in subset for grid data - Java based – Interoperable <ul style="list-style-type: none"> - VisAD rendering - Compact Application - Install is and plugin manager make customization easy too - Geospatial transforms supported 	<ul style="list-style-type: none"> - Point data format unstable - GUI interface is clunky - Adding New Reader is difficult - Slow rendering/loading

B. Considerations for data ingest, transformation and client access

The Northern Gulf Institute (NGI) Ecosystem Data Assembly Center⁸ (EDAC) provides the IT framework for the HabitatSpace data ingest, format transformation and client access. Fig.3 shows the schematic initially proposed for the data flow. In this model, scientists provide data files to the EDAC which are transformed to standard formats and served to users for direct access by the HabitatSpace clients.

In practice, project partners provide vector data in documented ASCII file formats to the EDAC via ftp. Data are automatically gathered from the ftp, transformed to an ESRI® File Geodatabase (FGDB) for the ArcGIS™ client, and also to NetCDF files for the IDV client. Circulation model data is accessible from the EDAC as part of another project. Bathymetry, coastline and other ancillary data files are widely available from public sources, and are not specifically processed as part of this project.

All NetCDF files produced as part of this project will be accessible from the EDAC THREDDS server, and may also be available to other (non-specific) applications. This IT research project is still in beta testing, and the data flow has not been fully optimized for general use at this time.

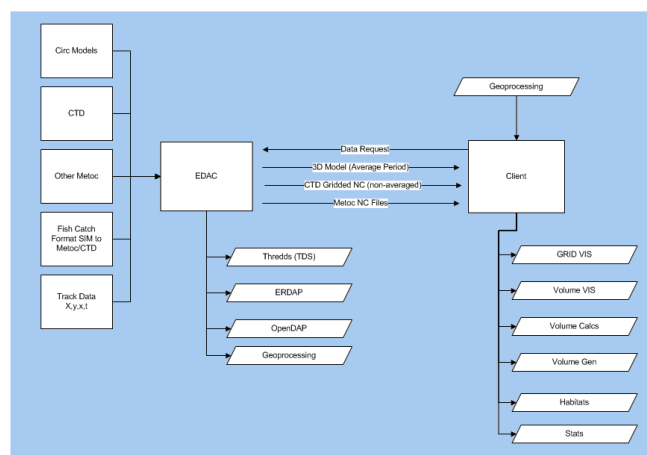


Figure 3 The NGI EDAC system provides data ingest and transformation, and serves data to the HabitatSpace client

⁸ The EDAC IT infrastructure supports ecosystem scientists, making observations and other related data available for research support. (last accessed 8/28/09) <http://edac.northerngulfinstitute.org/> last accessed 8/30/09

HabitatSpace integrates a wide range of data parameters from many sources. An overview of data currently integrated into HabitatSpace includes:

- Circulation models: Navy Ocean Current Model (NCOM) is a source of sea surface height, temperature, and salinity, as well as current speed and direction. The Regional Ocean Model System⁹ (ROMS) NEP4 (10 km resolution)
- In situ physical data: temperature and salinity data collected using a Seacat Profiler CTD¹⁰ provides information on environmental factors affecting larval development and survival;
- Meteorological sensors: Shipboard sensors and data buoys provide environmental parameters such as wind speeds and insolation. Winds create turbulence that may affect habitat. Insolation affects algal growth and the ability of visual feeders to capture prey.
- Biological data: Rough counts of larval abundance provide information for quick inter-annual comparisons of abundance and growth.
- Particle simulations: Calculated paths of larvae as they drift as particles before becoming strong and large enough to swim. Calculated externally and provided to HabitatSpace as an ASCII file.

For this year's project, scientists elected to study pelagic habitats in the Shelikof Strait (for Walleye Pollock). NOAA's EcoFOCI¹¹ program conducts biannual biology surveys on a fixed grid in this region. Data from these surveys was combined with historic information from other resources to test data throughput. Once standards for ingest and output were developed, methods were codified to ingest data and serve to the HabitatSpace clients. Methods were tested with the EcoFOCI survey data from May 2009. At the time of this writing, plans are to further test the process in beta operations during an upcoming survey.

IV. RESULTS

HabitatSpace clients are being developed in both ESRI® ArcGIS™ and IDV. Each system currently meets a subset of the HabitatSpace requirements, and each is operating in beta test mode¹². As anticipated, each version offers strengths and weaknesses, particularly in terms of multidimensional visualization and statistical analysis capabilities.

A. ESRI® HabitatSpace Clients

Two versions of HabitatSpace were created using ESRI® ArcGIS™. One is a desktop extension and the second is an ESRI® ArcGIS™ Engine runtime client. Both applications use the ArcObjects API for basic GIS functionalities such as ingesting data, writing shapefiles, displaying and color coding ship tracks and contouring datasets. Statistical analyses such as mean center in X, Y and Z can be calculated using tools in the ArcGIS Statistical Toolbox.

Once installed and running as part of the ArcGIS™ desktop suite, the HabitatSpace extension appears on the ArcGIS toolbar. The extension provides a set of tools and menus to guide users through ingesting specific data parameters and customizing data rendering. Statistical analysis and some multidimensional visualization capabilities are integral to the software with the addition of ESRI® extensions (Spatial Analyst™ and 3D Analyst™.) and are not further customized as part of the HabitatSpace ArcGIS™ desktop extension; users must know how to work with data in these tools to be able to accomplish statistical tasks.

An ArcGIS™ Engine application has also been developed for HabitatSpace. This has been compiled with ESRI® Statistical Analyst™ and 3D Analyst™ to gain the desired functionality. The runtime license package required to operate this version is relatively inexpensive when compared to the cost of the full ArcGIS™ software suite. It is also a very lightweight package that installs easily and relies on Internet connectivity to obtain the most basic data files such as a world map or coastlines. Statistical functions explicitly added into the HabitatSpace client include Hot Spot analysis (Fig.4) and Kriging (Fig 5.) A Users Guide assists users in loading, visualizing and analyzing the data [4].

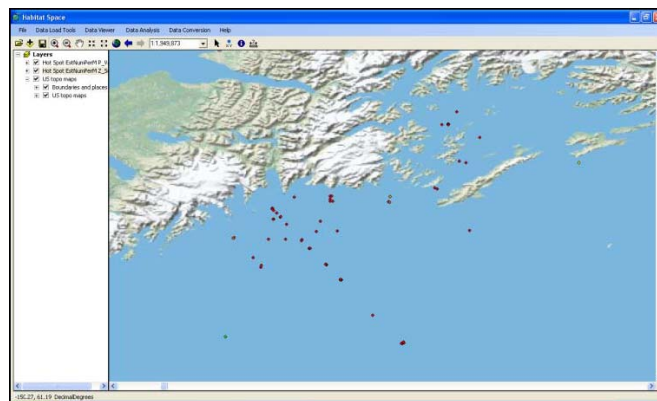


Figure 4 Example of Hot Spot analysis using fish catch data

⁹ The Regional Ocean Modeling System (ROMS) is a regional ocean general circulation modeling system. (last accessed 8/28/08) <http://www.ocean-modeling.org/index.php?page=models&model=ROMS>

¹⁰ SeaBird manufacturing (last accessed 8/28/09) http://www.seabird.com/pdf_documents/datasheets/19plusV2brochure.pdf

¹¹ EcoFOCI is an ongoing NOAA program established to study the factors that cause variability in the recruitment success of commercially valuable fin and shellfish in Alaskan waters. (Last accessed 8/28/09) <http://www.ecofoci.noaa.gov/>

¹² Beta testing notes: All HabitatSpace client testing to date has been limited to personal computers running a version of the Microsoft operating system. Testers must have system administrator privileges to install the software, and licenses as necessary.

The Hot Spot Analysis Tool compares the spatial distribution of a specific, user selected data field, and determines the value groupings. This tool analyzes the trends of both the spatial and variable characteristics of the chosen data set and field. This analysis can then be used to determine areas that have had a higher (or lower) than normal average of values. Identifying spatial trends facilitates cause and effect analysis. The example in Fig. 4 shows calculations of the spatial distribution of Fish Catch data using the Euclidean¹³ Distance method. Processing times may vary from five minutes to twenty minutes or more dependent upon the volume of data selected for processing.

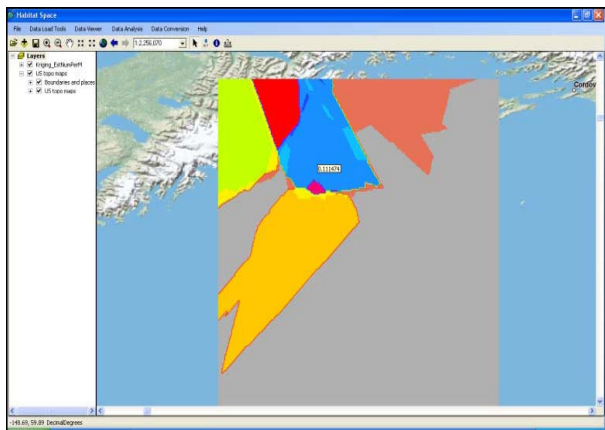


Figure 5 Example of surfaces generated with Kriging, analysis of fish catch data

Although this approach holds interest and seems promising, the work was not readily transferrable to this investigation, and project resources do not permit full evaluation.

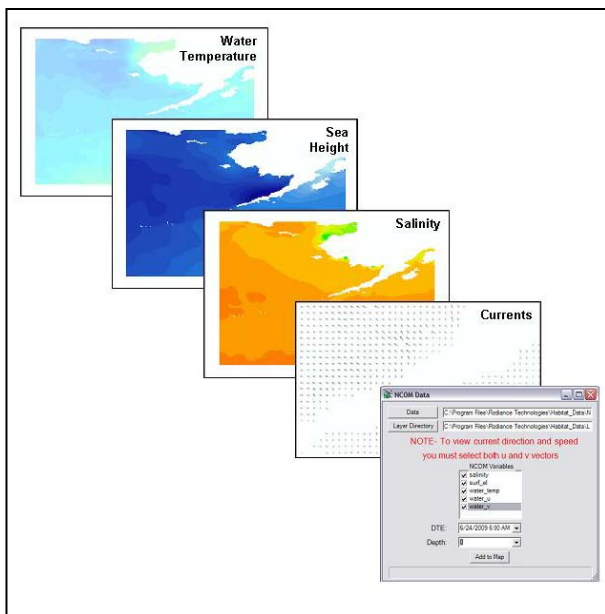


Figure 6.NCOM files in NetCDF format are ingested into HabitatSpace and displayed as individual layers. The User Interface allows choice of data parameters and display options.

Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. Unlike other interpolation methods, Kriging involves an interactive investigation of the spatial behavior of the phenomenon represented by the z-values before you select the best estimation method for generating the output surface. Fig. 5 displays “out-of-the-box” results when Kriging is applied to the fish catch data layer.

As anticipated, this software package has native limitations in the ability to generate, display and analyze data volumes. Researchers at the University of Texas, Austin have performed extensive groundwater assessments involving implementation of the QHull¹⁴ algorithm. By using lengths and areas from GIS data to convert water measurements on the fly to volume and time, data from multiple sources have been integrated. Reportedly, historic and real-time data from gauges are compared with model data, and this data can participate in volumetric estimates of the water as it moves through the hydrologic framework[5].

NCOM model runs in NetCDF format may be ingested into the ESRI® version of the HabitatSpace client(s), where the data will be extracted from NetCDF and displayed as individual layers (Fig. 6.) The UI shown in Fig. 6 is indicative of the standard UI, developed for HabitatSpace users to customize data ingest and display in ArcGIS™.

The process of reading the original NCOM NetCDF file and transforming the data to layers may take considerable time, dependent on the size of the initial grids selected for display. External (to the client) tools are available for subsetting the original NetCDF file prior to ingest¹⁵. NCOM Region 6 (Pacific) covers a large area, and users are advised to subsample the data prior to initiating the ingest and transformation process. In particular, processing current speed and direction takes longer than other data parameters.

Investigation into methods to seamlessly create surfaces and volumes and to perform analysis on the integrated data is ongoing.

¹³ Euclidean (as the crow flies)—the straight-line distance between two points.

¹⁴ Qhull is a general dimension code for computing convex hulls. (last accessed 8/28/09) <http://www.qhull.org/>

¹⁵ NetCDF Kitchen Sink version 3.3 performs many common tasks for the rapid manipulation and analysis of NetCDF data.. (last accessed 8/28/09) http://www.unidata.ucar.edu/mailing_lists/archives/netCDFgroup/1995/msg00093.html

B. IDV HabitatSpace Client

The Unidata Integrated Data Viewer¹⁶ (IDV) is Unidata's newest scientific analysis and visualization tool, built upon a freely available Java™ framework and reference application, and the VisAD library. IDV provides 2- and 3-D displays of geoscientific data that operate in a stand-alone or networked application.

With the exception of the particle simulation data, the IDV-based visualization module can simultaneously render all of the required HabitatSpace data sources (Fig. 7), requiring varying levels of modifications.

The data connection to NCOM takes advantage of the fact that NCOM data are regularly gridded, CF-compliant and are stored in a single file. NCOM ingest and 3D display works 'out-of-the-box.'

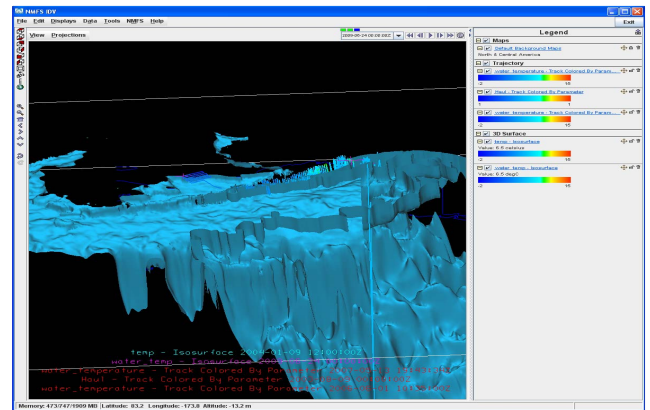


Figure 7 IDV can simultaneously render all the required data sources

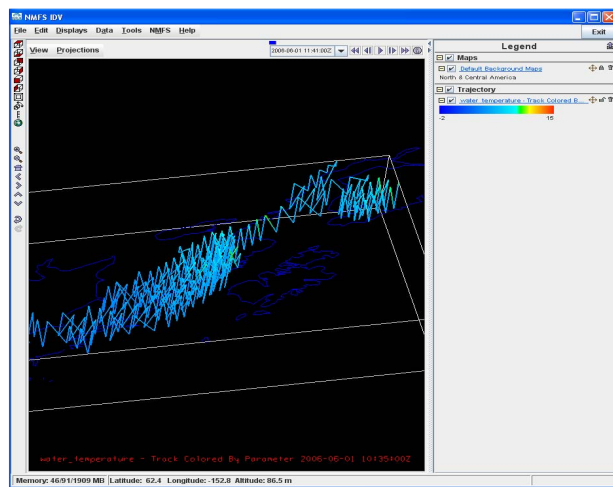


Figure 8 CTD profiles displayed in IDV

Displaying trackline data in IDV requires modifications. For purposes of this project, fish catch, CTD profiles, and MET observations are affected. There is no CF standard for point data. The existing IDV trackline data standard requires specific variable names that are not aligned with oceanographic variable names. NcML¹⁷ is used to modify the trackline data as follows:

- change coordinate variable names;
- change the dimension name to 'time';
- define upward positive;
- add the CF "cdm_data_type" attribute; and
- add the CF "Conventions" attribute (for MET observations)

Further, IDV does not yet support multiple tracks per file. The display of CTD profile data is shown; the end of each cast appears connected to the start of the next cast (Fig. 8).

The particle simulations file has incompatibilities that cannot be solved using only NcML. The IDV track data standard does not support this format because: the time variable is a one-D array; and the Lat/Lon coordinates are two-D arrays. Full implementation of the particle simulations data display will await the new CF standard for point and track NetCDF files.

V. CONCLUSIONS AND FUTURE EFFORTS

The output from oceanic circulation models provides both scientifically important views of the ocean and the basis for further calculations by other models and analyses using the original outputs. For example, the Regional Ocean Model System (ROMS) model is used to study circulation patterns in a number of important ecosystems. ROMS output can be coupled with a variety of other models, such as particle tracking models (particle simulations), to study the transport of biological particles, including fish larvae, and non-living particles, which might be sediments or contaminants. The goal of the Habitat Space project is to create a seamless IT framework for integrating the output from various circulation models with the output from particle tracking models and other ecosystem information to define EFH in multiple dimensions.

This type of tool, designed to assist scientists in the identification, monitoring and conservation of EFH, is the first step in responding to changes caused by climate change, environmental variability and increased anthropogenic modification of the oceans. Benefits of this modeling include providing needed technologies and tools to support planning for how chronic, secular change, as well as acute catastrophic events, affect individual EFH sites and what measures are needed to mitigate the effects.

¹⁶ The Integrated Data Viewer (IDV) from Unidata is a Java(TM)-based software framework for analyzing and visualizing geosciences data. (Last accessed 8/28/09) <http://www.unidata.ucar.edu/software/idv/>

¹⁷ NcML is an XML representation of NetCDF metadata. (last accessed 8/28/09) <http://www.unidata.ucar.edu/software/netcdf/ncml/v2.2/Tutorial.html>

The proposed solution is designed to provide enhancements to existing tools, many developed in earlier HPCC-funded projects. IT research efforts to date have yielded mixed results. As discussed, both the ESRI® and Unidata implementations of HabitatSpace each offer strengths and weaknesses.

The ESRI® ArcGIS™ system is unparalleled for familiarity and ease of use. End-users have a wide range of native options for display customization for both raster and vector data parameters. The HabitatSpace clients are easy to install, assuming one has both system administrator permissions and the prerequisite software and licensing [4]. While past research [2] and elements of current activities clearly demonstrate the capacity for GIS systems to run, analyze, and visualize (Fig 9) output from particle tracking models (particle simulations that use the output of these circulation models), these same systems appear unable to robustly support the true multidimensional visualization and analysis which is the next logical step in the scientific process. Future work will focus on extending ArcObjects™ customization for enhanced capabilities.

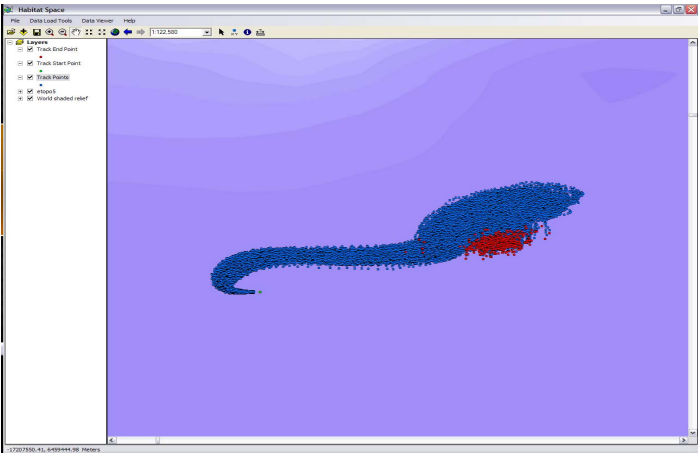


Figure 9 Theoretical paths of Pollock larvae released at the lower left of the image. The red dots show the final location of the larvae.

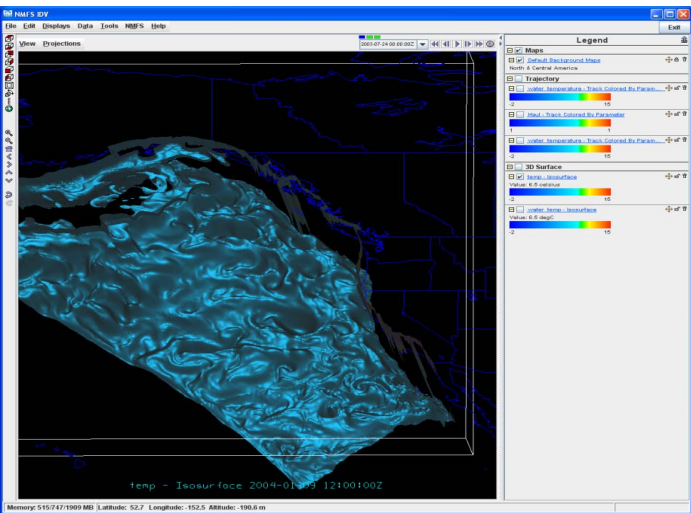


Figure 10 ROMS NEP4 output displayed as a 3D surface in IDV

The IDV software has demonstrated a strong capacity for multidimensional visualization of model output. This is the primary reason the software was selected for research, and it did not disappoint. In addition to the native display of NCOM data discussed, IDV displayed ROMS NEP4 output (Fig. 10), a more challenging effort by far due to the curvilinear nature of the grid. Programmer support was necessary to accomplish this task. Sample ROMS NEP4 grid and data files were aggregated (using NcML, time steps were aggregated with the grid file). IDV could not draw the vectors associated with the ROMS staggered velocity. However the interesting display holds promise.

Planned future efforts include continuing to work with Unidata/IDV on data standards for point and track data, and for support of staggered model velocity data. Further interface development will include developing Jython script tools for threshold operations on data parameters and development of R-based statistical analysis of threshold volumes.

At the project’s outset, factors determining the success of the project were identified as: a) the degree of adoption of the tools by scientists making EFH determinations; b) the ease with which the tools can be integrated with existing technologies, c) the ease with which the tools can be generalized for use with other types of volumetric analyses; and d) the degree to which the tools are adopted by NOAA scientists and their collaborative partners.

In FY10 the visualization and analysis capabilities developed under this proposal will see extensive beta testing by NOAA EcoFOCI project scientists and potentially by other NCDDC and NGI partner organizations as well. These prototypical tools will become available to the EFH community for habitat analyses, and have the potential to be applicable to a number of NOAA projects. Community interest is strong, and with the distribution of the framework, the authors hope to obtain feedback on the tool capabilities, which may further guide direction forward.

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REFERENCES

- [1] Vance, T.C., S. Mesick and D. Reusser. 2009. "HabitatSpace - GIS-based multidimensional habitat modeling in the ocean and atmosphere." AMS annual meeting, 25th International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology. Phoenix, AZ., Jan 2009.
- [2] Vance, T.C., S. L. Cross, B. A. Megrey, S. M. Mesick, and C. W. Moore. 2008. *GeoFish – visualization and analysis of particle tracking model output for fish and shellfish larvae*, ICES 2008 Annual Science Conference - theme session R (Data Management) Halifax, Nova Scotia. 22-26 September 2008.
- [3] Vance, T.C., N. Merati, S. Mesick, C.W. Moore, and D. Wright. 2007. *GeoModeler: Tightly linking spatially-explicit models and data with a GIS for analysis and geovisualization*. In 15th ACM International Symposium on Advances in Geographic Information Systems (ACM GIS 2007), Seattle, WA, 7–9 November 2007.
- [4] *Habitat Space ArcGIS Engine Application User's Guide: Instruction Guide to Load Fisheries Data into ESRI ArcGIS Application for Visualization and Analysis*. Prepared by Radiance Technologies Inc. Aug 1, 2009. Unpublished draft.
- [5] Brink, T., Stewart, K., Hampson, J., Maidment, D. *Integrating Time Series in Arc-Hydro Water Resources Information Systems*. 2006. *GIS in Source Water Susceptibility Assessment*. In: Proceedings of the Twenty-Sixth Annual ESRI User Conference, 2006. Unpublished.